Strategy Research Project

THE SPACE DEBRIS CRISIS: TIME FOR AN INTERNATIONAL TREATY

BY

MR. EDGAR M. HOLLANDSWORTH III
Defense Intelligence Agency

USAWC CLASS OF 2011

Prudens Futuri

U.S. Army War College, Carlisle Barracks, PA 17013-5050

The U.S. Army War College is accredited by the Commission on Higher Education of the Middle State Association of Colleges and Schools, 3624 Market Street, Philadelphia, PA 19104, (215) 662-5606. The Commission on Higher Education is an institutional accrediting agency recognized by the U.S. Secretary of Education and the Council for Higher Education Accreditation.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* 23-03-2011	**2. REPORT TYPE** Strategy Research Project	**3. DATES COVERED** *(From - To)*

4. TITLE AND SUBTITLE The Space Debris Crisis: Time for an International Treaty	**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Mr. Edgar M. Hollandsworth III	**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Lieutenant Colonel Gregory D. Hillebrand Department of Military Strategy, Planning, and Operations	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army War College 122 Forbes Avenue Carlisle, PA 17013	**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution A: Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The growth of man-made debris in Earth's orbits has accelerated in the past decade to the point that uncontrolled cascading collisions between debris and active spacecraft is now occurring in low Earth orbit (LEO). A Chinese anti-satellite (ASAT) weapon test in 2007 and the Cosmos-Iridium collision in 2009 added significantly to the mass of debris in LEO. The space powers are now confronted with a stark choice: either work together to actively manage their use of the space environment, or learn to live without it. Current national policies and practices, space law, and international voluntary guidelines for mitigation of space debris offer a necessary, but insufficient, strategic solution to the space debris crisis. A radically new governance regime, codified in a legally-binding treaty, is needed to actively manage the space environment around Earth. The main objective of this treaty would be to ensure Earth's orbits do not become so congested that their use would become too dangerous or expensive. This regime would require space powers to cooperate to share limited orbital resources and space situational awareness information to a degree that has never been attempted before.

15. SUBJECT TERMS
satellites, law, environment, mitigation, NASA, ESA, UN, IADC, SSA, LEO, ASAT, ISS, Space Shuttle, China, orbit

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT UNCLASSIFED	**b. ABSTRACT** UNCLASSIFED	**c. THIS PAGE** UNCLASSIFED	UNLIMITED	34	**19b. TELEPHONE NUMBER** *(include area code)*

USAWC STRATEGY RESEARCH PROJECT

THE SPACE DEBRIS CRISIS: TIME FOR AN INTERNATIONAL TREATY

by

Mr. Edgar M. Hollandsworth III
Defense Intelligence Agency

Lieutenant Colonel Gregory D. Hillebrand
United States Air Force
Project Adviser

This SRP is submitted in partial fulfillment of the requirements of the Master of Strategic Studies Degree. The U.S. Army War College is accredited by the Commission on Higher Education of the Middle States Association of Colleges and Schools, 3624 Market Street, Philadelphia, PA 19104, (215) 662-5606. The Commission on Higher Education is an institutional accrediting agency recognized by the U.S. Secretary of Education and the Council for Higher Education Accreditation.

U.S. Army War College
CARLISLE BARRACKS, PENNSYLVANIA 17013

ABSTRACT

AUTHOR: Mr. Edgar M. Hollandsworth III

TITLE: The Space Debris Crisis: Time for an International Treaty

FORMAT: Strategy Research Project

DATE: 23 March 2011 WORD COUNT: 6,589 PAGES: 34

KEY TERMS: satellites, law, environment, mitigation, NASA, ESA, UN, IADC, SSA, LEO, ASAT, ISS, Space Shuttle, China, orbit

CLASSIFICATION: Unclassified

The growth of man-made debris in Earth‟s orbits has accelerated in the past decade to the point that uncontrolled cascading collisions between debris and active spacecraft is now occurring in low Earth orbit (LEO). A Chinese anti-satellite (ASAT) weapon test in 2007 and the Cosmos-Iridium collision in 2009 added significantly to the mass of debris in LEO. The space powers are now confronted with a stark choice: either work together to actively manage their use of the space environment, or learn to live without it. Current national policies and practices, space law, and international voluntary guidelines for mitigation of space debris offer a necessary, but insufficient, strategic solution to the space debris crisis. A radically new governance regime, codified in a legally-binding treaty, is needed to actively manage the space environment around Earth. The main objective of this treaty would be to ensure Earth‟s orbits do not become so congested that their use would become too dangerous or expensive. This regime would require space powers to cooperate to share limited orbital resources and space situational awareness information to a degree that has never been attempted before.

THE SPACE DEBRIS CRISIS: TIME FOR AN INTERNATIONAL TREATY

On October 4, 2017, sixty years after the launch of the first spacecraft, Sputnik 1, the following report appeared in the "President‟s Daily Brief:"

> At 0116 EDT, the Chinese reconnaissance satellite BUTTERFLY-3 went offline unexpectedly over South America. Within minutes, the U.S. Space Surveillance Network (SSN) identified a cloud of over 500 pieces of new debris along the satellite‟s projected orbit. The cause of the break-up could not be immediately confirmed, but analysis of the debris field pattern suggests a collision with untracked space debris occurred, though an onboard explosion cannot be ruled out. The timing of the incident could not have been worse. Because of the current US-Chinese confrontation over the Spratly Islands, and an ongoing US naval exercise in the South Atlantic, Chinese authorities quickly inferred a worst-case scenario was unfolding: that the US Navy had intercepted BUTTERFLY-3 as an opening salvo in a pre-emptive space control offensive. In response, China elevated its military alert status to its highest level, activated its own anti-satellite (ASAT) launch facilities, and began a mass mobilization of the Peoples‟ Liberation Army. Most ominously, there are now unambiguous indications of preparations on China‟s east coast for an invasion of Taiwan….

While this is merely a postulated scenario, it is all too plausible. Under a wide range of possible circumstances, space debris can destroy space-based capabilities vital to the national security of the U.S. and other space-faring nations.[1] In this example, a collision with space debris exacerbated an ongoing crisis and led two space powers to the brink of war. However, even in a non-crisis situation, where the source of a collision is universally recognized as space debris, there are strategic considerations of national responsibility and compensation that all involved parties are required to address under existing space law.[2]

All space powers share a common interest in safe access to space. The space domain provides mankind a host of benefits on which our global economy and quality of life deeply depend. The worldwide $250 billion per year space-services industry provides “financial communication, global-positioning navigation, international phone connections, Google Earth pictures, television signals and weather forecasts.”[3] Government space programs provide such services as military threat warning, precision navigation and targeting, weather forecasting, and secure communications . In the 21st century, US military power became fully dependent on space support:

> For the first time in the history of warfare the majority of weapons used by U.S. and British forces [during Operation Enduring Freedom] relied on space based guidance systems to reach their targets.[4]

In addition, National Aeronautics and Space Administration (NASA) records alone list over 1,900 economic “spin offs” from space research and development projects since 1976; these include solar power, cardiac pacemakers, satellite TV and robotics that are vital to developed nations, as well as innovations like air and water purification systems that save lives and improve quality of life in emerging countries.[5] Loss of access to space would jeopardize these valuable space services and prevent future spin offs.

The financial and operational viability of all government and private sector space programs depends on a space environment that is sufficiently free from the threat of space debris impacts to make new space projects feasible, safe, and cost-effective. Earth‟s orbits are not owned by any nation; they are a valuable and limited resource for all.[6] The problem is, at some point during this century, the growth of man-made space debris in low earth orbit (LEO) will threaten mankind‟s ability to access and safely utilize the space commons. Because of this, the space powers are now confronted with a stark choice: either work together to actively manage their use of the space environment, or learn to live without it. The latter unfortunate outcome would leave all nations with no alternative but to depend exclusively on terrestrial, maritime, and airborne architectures to provide many of the services formerly delivered through space systems, at higher cost and reduced capability. That there is sufficient self-interest, good will, readiness, and time for the space powers to cooperate to prevent this outcome, and achieve the desired endstate of a safe and sustainable orbital environment, is the hopeful assumption of this paper.

In the face of the common and real threat of the future closure of LEO to human activity due to space debris, a binding international treaty on space environmental management (SEM)--with mechanisms for orbital resource allocation, confidence-building measures, crisis management, and effective enforcement--is required to manage Earth"s orbits in a way that ensures their sustainable use. To support this thesis, this paper describes how the uncontrolled increase in space debris is endangering man"s access to, and use of, low Earth orbit (LEO). It will then review and assess the sufficiency of current US and international voluntary approaches to mitigating the crisis and identify how an international treaty on SEM would rectify critical gaps and shortfalls in the current voluntary approach. Building on this analysis, this paper will propose key provisions for a SEM treaty, and conclude by identifying potential impediments to ratification and implementation for future study.

<u>The Space Debris Crisis</u>

The problem of space debris is not new. It began as soon as the first satellite, Sputnik 1, stopped transmitting to Earth in late October, 1957 and fragmented into eight pieces in January, 1958 before burning up in the atmosphere later that month.[7] The growth of debris accelerated in June, 1961, when the first explosion of a U.S. booster rocket took place in LEO and generated 296 pieces of debris.[8] While explosions of rocket stages are historically the primary source of space debris (40 percent of all debris), satellite explosions due to on-board mechanical failure and fragmentation caused by ASAT testing have also contributed greatly to the problem.[9] The Chinese test of an ASAT against a defunct Chinese satellite (Fengyun 1C) in 2007 produced 2,841 pieces of cataloged debris.[10] It was only the latest episode in a long history of ASAT testing in space. The Soviet Union detonated its Fractional Orbital Bombardment Satellite interceptors, developed in the 1970s, nine times, and the U.S. tested an ASAT in 1985.[11]

Dead spacecraft, debris in their own right, also clutter Earth"s orbits. Their presence is also generating new debris. In 2009, a "crash between a defunct Russian Cosmos satellite and an Iridium Communications satellite left 1,500 pieces of junk, each whizzing around the Earth at 4.8 miles a second and each capable of destroying more satellites."[12] Combining the Chinese ASAT test with the Cosmos-Iridium collision data, the amount of generated debris larger than 1 centimeter is over 250,000 pieces, "concentrated in the heart of LEO but spread across the entire region."[13]

The Cosmos-Iridium collision in 2009 may prove to be a harbinger of many more to come. In 1978, Dr. Donald J. Kessler, later Chief of NASA"s Orbital Debris Program Office, predicted an increase in space debris, beyond a critical tipping point, would cause a chain reaction of uncontrolled cascading collisions in orbit (later referred to as the "Kessler Syndrome"); left unchecked, these collisions would eventually create a dangerous ring of debris around the Earth.[14] NASA data from March, 2010 in Figure 1 below shows the startling growth of debris in LEO. The chart highlights the recent "contribution" of the Chinese ASAT and Cosmos-Iridium events to the debris problem.

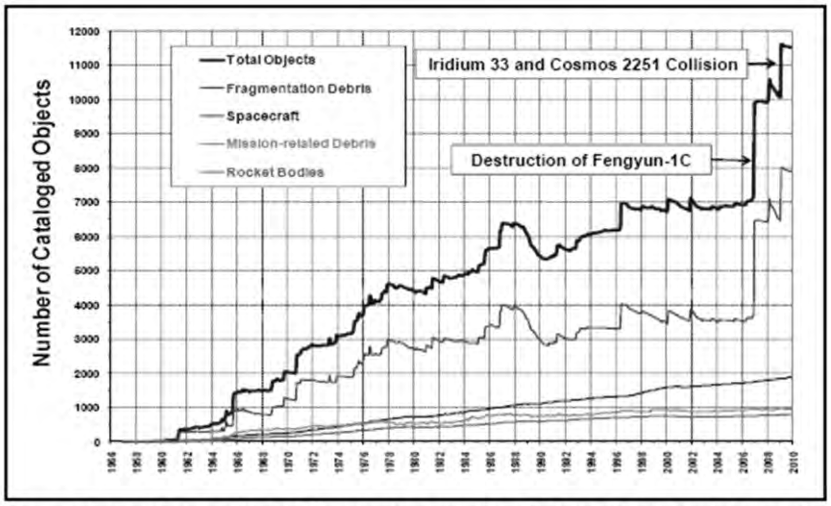

Figure 1. Growth of the cataloged LEO space object population (objects with orbital periods less than 127 minutes).

Figure 1. Growth of Cataloged Space Objects in LEO, 1961-2010[15]

This data reflects only objects large enough to be cataloged at LEO, 10cm or larger in diameter, which also are those considered massive enough to generate “significant secondary particles in a collision.”[16] The scale of the problem is much larger than this. NASA estimates that

> There are more than 20,000 pieces of debris larger than a softball orbiting the Earth. They travel at speeds up to 17,500 mph, fast enough for a relatively small piece of orbital debris to damage a satellite or a spacecraft. There are 500,000 pieces of debris the size of a marble or larger. There are many millions of pieces of debris that are so small they can‟t be tracked.[17]

According to European Space Agency (ESA) officials, “1 mm objects [in orbit] can damage a satellite sub-system, 1 cm objects are likely to disable satellites while 10 cm objects are likely to cause catastrophic satellite break-ups.”[18] NASA Chief Scientist for Orbital Debris Nicholas Johnson observed non-trackable debris poses the greatest risk to NASA space operations.[19] Damage from tiny paint flecks forced NASA to replace several space shuttle windows.[20]

In 2010, Kessler observed the trend of random hypervelocity collisions between cataloged space objects (four since 1991); his analysis comports well with his 1978 predictions based on observed growth in the number of new man-made objects in space (approximately 300 annually).[21] Using a NASA environmental model, Kessler calculated the next collision will occur between 2012-2015, and determined the frequency of collisions will accelerate.[22] Kessler"s 2010 research concluded ominously:

> …the results are consistent with the earlier predictions that the current [debris] environment is above a critical threshold. During the 200 years [from 2010 to 2210]…the results appear to be a runaway environment.[23]

Figure 2 below, which assumes no additional space launches after 2004, projects the automatic growth of fragments from cascading collisions that will be capable of causing catastrophic damage to spacecraft if nothing is done.[24] To prevent an increase in LEO debris, Kessler calculated 90 percent of all future launches would need to adhere to current UN debris mitigation guidelines (described later), and five cataloged objects per year would have to be eliminated through active debris reduction (ADR) measures.[25]

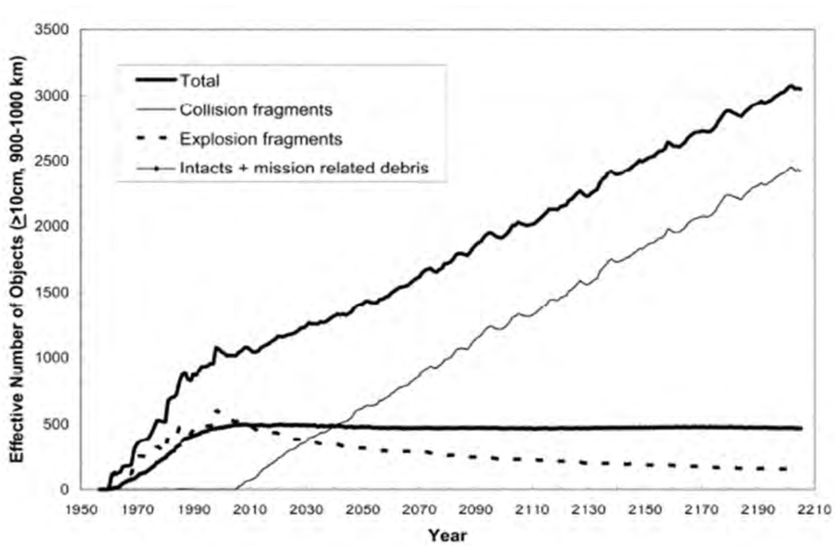

Figure 2. Projected Growth of Objects Larger than 10 CM in 900-1000 KM Orbit[26]

The growth of space debris in LEO is putting vital space operations at risk. NASA reported significant increases in the number of predicted "conjunctions" between debris and the International Space Station (ISS) and space shuttle since 2008.[27] In response to conjunction forecasts, the ISS and shuttle have been forced to maneuver at greater frequency. Over the 9-year period of 1998-2007, the ISS performed only four avoidance maneuvers.[28] Since 2007, it has already performed three (October, 2008[29], March, 2009[30], and most recently in October, 2010[31]). The Space Shuttle had an average of two conjunctions per month from 1998-2007; in 2008 and 2009, it averaged seven.[32] ESA is now maneuvering its satellites approximately once a month.[33] Along with weather and equipment malfunctions, space debris is now a cause for launch delays.[34] The challenge of space debris is not limited to civilian space programs. It is starting to jeopardize US national security space capabilities as well. According to Deputy Defense Secretary William Lynn:

> A decade into the 21st century, space is characterized by what I have called the three Cs: congested, contested, and competitive. Congested because 60 nations now have a presence in space…the skies over earth are so cluttered with debris that further collision could eventually put some usable orbits in jeopardy.[35]

National and private-sector ambitions for greater presence in space during the next decade will exacerbate the crisis by increasing orbital crowding. The international demand for orbital real estate is skyrocketing. However, like terrestrial real estate, there is only so much to go around, and no process in place to ration available space in LEO. By 2019, the average number of annual satellite launches worldwide is expected to grow from 77 in the past decade to 122; 808 of the total of 1,220 launches during the next decade will be government-sponsored, of which 46 percent [approximately 372] will place spacecraft in LEO.[36] Many of these launches will transport multiple payloads.

The addition of so many new satellites and other objects will invariably accelerate collisional cascading and raise the ADR requirement beyond five per year. All trends point to one inescapable conclusion: unless concerted action is taken now by all space powers to reduce debris and actively manage use of the space environment around Earth, LEO will eventually become so crowded it will be too risky or expensive to launch into it. It will thus become off-limits to human use indefinitely.

Is the Current US and International Response to the Space Debris Crisis Sufficient?

Throughout the Space Age, space powers were aware of the growth of orbital debris. However, as long as the debris cloud was relatively small and the U.S. was able to locate and track individual pieces with moderate precision, provide sufficient early warning to operators, and maneuver spacecraft to avoid collisions, national space authorities deemed the risk manageable. Now that the risks are growing and may become unmanageable, US policy makers have begun to express concern over the risks of space debris to US and international economic, scientific, and national security interests in space. Accordingly, they have begun to give higher priority and greater visibility to space debris control in national policies. As presented in the 2010 US *National Space Policy*: "the United States considers the sustainability, stability, and free access to, and use of, space vital to its national interests."[37] The third goal of the space policy makes mitigating space debris a high-priority objective:

> Strengthen stability in space through: domestic and international measures to promote safe and responsible operations in space; improved information collection and sharing for space object collision avoidance; protection of critical space systems and supporting infrastructures...and strengthening measures to mitigate orbital debris.[38]

In November, 2010, Deputy Assistant Secretary of State Frank Rose outlined the US Government strategy to implement this goal:

- Increase US engagement with the UN, other governments, and non-governmental organizations
- Lead development and gain international acceptance of debris mitigation standards
- Work with the EU and other nations to study "long-term sustainability" in the context of the Scientific and Technical Committee of the Committee on the Peaceful Uses of Outer Space (COPUOUS) and produce "best practice guidelines"
- Work with other space powers on "research and development of technologies and techniques to mitigate on-orbit debris, reduce hazards, and increase our understanding of the current and future debris environment."[39]

Each of these four lines of effort (LOE), assessed below, is necessary for the US--working with other space powers--to solve the space debris crisis. The question is whether these LOEs, collectively and in coordination with other space powers, are sufficient to reach the endstate of a safe, managed space environment.

US Engagement with UN and Other Space Powers. US engagement with the UN and other governments on space debris is already a well-established practice, and has often focused on gaining acceptance of debris mitigation standards. The two LOE are thus considered together here. The United Nations (UN) has taken a leading role developing space debris mitigation guidelines. After 13 years of scientific investigation, the UN General Assembly endorsed UN Resolution 62/217 in 2007. This promulgated non-legally binding debris mitigation guidelines proposed by the Committee on the Peaceful Uses of Outer Space (COPUOS).[40] These are: "limit debris released during normal operations," "minimize the potential for break-ups during operational phases," "limit the probability of accidental collision in orbit," "avoid intentional destruction and other harmful activities," "minimize potential for break-ups resulting from stored energy," "limit the long-term presence of spacecraft and launch vehicle orbit stages in the low Earth-orbit (LEO) region after the end of their mission," and "limit the long-term interference of spacecraft and launch vehicle orbital stages with the [GEO] region after the end of their mission."[41]

In promulgating these, COPUOS relied heavily on input from the Inter-Agency Space Debris Coordination Committee (IADC).[42] The IADC describes itself and its mission as

> …an international governmental forum for the worldwide coordination of activities related to the issues of man-made and natural debris in space. The primary purposes…are to exchange information on space debris research activities…to facilitate opportunities for cooperation in space debris research, to review the progress of ongoing cooperative activities, and to identify debris mitigation options.[43]

The IADC Charter does not invest the IADC with implementation responsibilities but opens the door to an international convention: "any specific cooperative activities endorsed by the IADC will be implemented through arrangements negotiated between member organisations."[44]

One of the IADC"s challenges is creating an internationally-accessible database of space objects. This is difficult due to the lack of agreed rules for sharing space situational awareness (SSA) information with the UN.[45] The IADC observed that this sharing "is currently insufficient to support either satellite conjunction assessments or predictions of object re-entries to the degree required for responsible operational decisions."[46] Nevertheless, IADC research already has shaped the international scientific consensus on the scale and severity of the debris problem as well as possible ways and means to deal with it. IADC debris mitigation guidelines have already been accepted by the UN and should form the core of a future international treaty.

Bilaterally, the U.S. State Department is leading U.S. efforts to improve collaboration with ESA, the European Union, and EU member states to improve US-European SSA interoperability, and is considering expansion of SSA cooperation to countries in the "Asia-Pacific and other regions."[47] Initial results of that effort occurred in November, 2010, when the US and Australia signed an SSA partnership agreement that committed Australia to upgrade SSA support to the US.[48] Enhancing multi-lateral SSA data acquisition and sharing is necessary for any space environmental management regime. But, by itself, it is not sufficient for implementing one.

Establishment of Space Debris Mitigation "Best Practices.". The third LOE, study "long-term sustainability" and produce "best practice" guidelines through the venue of the COPUOS Scientific and Technical Committee suggests no matter what the sustainability study may conclude, the intended outcome of the effort will be the same: voluntary guidelines. STSC has begun a long-term "work plan" on sustainability of outer space activities, which will include the development of [space object] databases as an "agenda item."[49] Unfortunately, some IADC member states do not make available all space surveillance network (SSN) data to the IADC, and thus to the international community at large. In turn, this places limits on the potential ability of the IADC and UN to monitor and assess the space environment. The validity of the results of any IADC sustainability study, and thus the recommended best practices, will be limited by the completeness and accuracy of the orbital object data nations choose to provide. Under current practices, the IADC risks understating its assessment of orbital congestion and inflating its assessment of sustainability. An international treaty should thus include a standard reporting provision for space objects that satisfies IADC technical requirements for future sustainability assessments. This provision would necessarily require fuller disclosure than currently required by the Convention on Registration of Objects Launched into Outer Space.[50]

Pursuit of New Technologies and Techniques. The fourth LOE, conduct research and development on space debris mitigation technologies and techniques, builds on a number of ongoing initiatives to explore and apply technical solutions to the problem of space debris proliferation. These include: mitigating the risk of collisions between debris and active spacecraft through collision avoidance maneuvers, enabled by SSA capabilities; preventing the generation of new debris by designing spacecraft and boosters with features that minimize its creation; designing spacecraft to accelerate their de-orbiting or transfer into "disposal orbits" at their end-of-life; and researching new technologies for ADR.

Use of warning and collision avoidance, enabled by SSA, has powerful adherents among international space community leadership. For ESA Director General Jean Jacques Dordain, managing the space debris problem requires advocating for improvements to European SSA capabilities and governance:

> ESA and European operators need to have [an SSA system] to help us to cope with the increasing problems caused by space debris….ESA has to take evasive action once every month to protect its satellites and does so on the basis of the advice from our friends the United States. But we cannot afford to continue to be blind to these dangers and governance will be an important factor in creating operational services.[51]

The US military has also begun to improve its tracking and collision warning capabilities through enhanced SSA. New Air Force systems are under development:

> …[Air Force Space Command] is filling critical SSA gaps with…programs to enhance our capability to detect, track, and identify smaller objects…like the Space Based Space Surveillance system, Space Fence and the Space Surveillance Telescope…[which] will give us additional capacity to search and track more on-orbit objects, improve our ability to predict potential collisions, provide safety of flight, and rapidly track and catalogue new foreign space launches.[52]

According to US Strategic Command, the Joint Space Operations Center of the Joint Functional Component Command-Space at Vandenberg Air Force Base, California began providing SSA data to commercial and non-US partners to support collision avoidance maneuvers late last year.[53] However, the growth of space debris is "outpacing" US efforts to upgrade its SSA capabilities:

> Despite significant SSA investments and advances to ensure [US] freedom of action in space, debris growth (4,600 objects in 1980; more than 21,000 today) continues to outpace SSA upgrades. This places a new urgency on improving SSA sensors and the technical and human capital resources performing collision avoidance analysis.[54]

Even the newer space powers have recognized the need for SSA. China reportedly installed "an alarm system to avoid collisions in space" on its first manned spacecraft, the Shenzhou 5.[55]

By itself, SSA does nothing to prevent the increase of debris in orbit from new launches. SSA is unsuitable for reducing the existing debris population, though it may assist ADR operations. Its contribution to collision avoidance depends on the ability of active spacecraft to maneuver in response to SSA warnings. The value of SSA as part of a global SEM program is limited to the extent that nations voluntarily make SSA data available to the global space community.

Given these limitations, the value of SSA in a SEM regime is limited to reducing the risk of catastrophic accidental collisions with active spacecraft that would add to the debris population. Even if space powers were to share SSA universally and without reservation, and even if its precision and resolution were increased, its usefulness as a warning tool would be limited: the majority of satellites could not avoid a collision because they cannot maneuver.[56] Whatever its advantages, even perfect SSA is no panacea for solving the space debris crisis.

Space vehicle design has also played a vital role in managing the debris problem. It has prevented explosions and enabled deorbiting or transferring spacecraft out of usable orbits at the end of their lives. During the early years of the Space Age, many upper stage booster rockets and fuel tanks exploded in or near LEO, leaving considerable debris in orbit. Subsequent advances such as "passivation" of spacecraft and launch vehicle orbital stages have rectified this issue to a large degree.[57] The US, European, and Russian space programs have adopted passivation techniques, although the implementation record has not been perfect.[58] Ironically, the Chinese ASAT program incorporates debris mitigation features! Since 2007, the program has started investing in "nonkinetic weapons…including high-powered lasers, microwaves, particle beams, and electromagnetic pulse devices, all intended to render enemy satellites inoperable without the debris field associated with kinetic-killing weapons."[59]

De-orbiting eliminates space debris. In a de-orbiting maneuver, "upper stages and spacecraft are placed in lower altitude orbits after their missions have been completed to accelerate their fall back to Earth."[60] Because of the amount of energy required to return to Earth, de-orbiting is only practical for LEO spacecraft.[61] Even for LEO spacecraft, the addition of de-orbiting thrusters can add significantly to the spacecraft budget in terms of cost, mass, and volume. German Society for Air and Space Travel Institute for Space Propulsion research concluded that requiring LEO satellites to have a de-orbiting function would have a significant impact on spacecraft design; for smaller satellites, the total mass could double.[62]

While NASA believes the orbital debris problem is much less severe in GEO, it notes many GEO satellites retain booster rockets to move them into disposal ("parking") orbits beyond the GEO constellation.[63] Transfer to parking orbits (i.e. re-orbiting) using on-board propulsion has proven successful for temporarily clearing usable GEO orbits. It requires spacecraft to maintain a reserve of propellant for end of life (EOL) maneuvering, and this shortens operational life and reduces profits for commercial interests.[64] Over time, however, like all satellites, these will eventually "fall back" to GEO, unless they have sufficient fuel to be launched outside of Earth‟s gravitational field. Perturbations in the disposal orbits of Global Positioning System (GPS) satellites at medium Earth orbit (MEO) caused by solar dynamics and orbital mechanics will likewise eventually result in expired GPS satellites assuming more elliptical orbits that will cross back through MEO and eventually LEO orbits.[65] In time, everything in Earth‟s orbit will come back and impact the Earth, so re-orbiting is a temporary solution.

Except for space debris in LEO which can be de-orbited and burn up on re-entry, man-made objects in Earth‟s orbit are destined to remain there for centuries or longer and will continue to pose a risk to operational spacecraft. Hence, there is an obvious need to actively manage the space environment indefinitely. An international treaty on SEM should therefore never expire, and it must enable management of debris in all orbits.

Kessler recommended active debris removal (ADR), the fourth technical solution, to help manage the population of debris in orbit. Some proposed government and industry-led system solutions for ADR are use of deorbiting modules, ground and air-based lasers, large area passive debris collectors, electrodynamic and momentum tethers, rendezvous debris removal, drag augmentation devices, space sails, and space-based magnetic field generators.[66] Examination of these technology options in depth is beyond the scope of this paper. However, a recent NASA study on the state of ADR technologies today was cautious, concluding that "the actual implementation of any mitigation measures to remove objects from space is very complicated. The cost and technical challenges are the two major obstacles that will not be resolved in the near future. Additional issues, such as ownership, liability, and policy, need to be addressed as well."[67] A SEM treaty would be the appropriate venue to address these additional issues. Lastly, ADR systems could be misused (or misconstrued) as ASATs (which they inherently are). Therefore, to prevent a possible international crisis, ADR must be employed under an internationally-recognized and acceptable process. This, too, should be defined in a SEM treaty.

Taken together, none of the four LOE are fully suitable or sufficient to deal with the heart of the problem: the need to regulate the space environment to ensure that the total number and mass of objects in LEO is kept below the threshold at which the number of random cascading collisions goes out of control. As described earlier, that limit has very probably already been reached. The unavoidable conclusion is that today‟s unenforced approach to space debris mitigation is too little and too late. The space powers now need a global regime to actively manage the use of Earth‟s orbits. This regime must compensate for the gaps and shortfalls in the current voluntary approach. From the preceding analysis, this regime must establish rules for sharing of

SSA data with the UN; make current IADC voluntary mitigation guidelines enforceable standards; ensure space object reporting standards satisfy IADC technical requirements for sustainability assessments; remain in force indefinitely; address ownership, liability and oversight of debris reduction operations; provide for an internationally-accepted method for employing ADR techniques that prevents their use as ASATs; and ensure enforceability for all of these provisions. Most importantly, it must provide a means to cap and manage the total amount of objects in Earth‟s orbits to ensure their sustainable use. There are several options for governing such a regime.

Towards an International Treaty on Space Environmental Management

Slowly but surely, a consensus among space powers is emerging that the current voluntary approach is not working and that an enforceable regime to manage the debris crisis is required. At the last meeting of the Legal Subcommittee of COPUOS in March, 2010, a number of national delegations proposed that COPUOS space debris mitigation guidelines should be further developed with the aim of establishing legally-binding rules.[68] In the absence of a full-blown treaty, which still appears to be beyond the near-term horizon, there are three incremental governance options available to manage the space environment, with varying degrees of enforceability and likelihood of success. These should be seen as stepping stones, not substitutes, to the goal of eventually achieving global ratification of a treaty. Only the fourth option, an international treaty, would be truly sufficient, though the hardest to achieve.

First, the status quo option, is voluntary adherence to current space law and voluntary compliance with current UN debris mitigation guidelines. Space powers have ratified a large body of international law governing human activities in space, beginning with the cornerstone Outer Space Treaty (OST) of 1967. Much of current space law expresses high-level principles, lacks any true enforcement mechanism, and does not enjoy universal ratification. It does, however, provide a legal foundation for future space treaties by promulgating core principles: international law applies in outer space (OST Article III), states are responsible and liable for activities in space (Liability Convention), and the UN is to maintain a registry of space objects (Registration Convention).[69] Despite these conventions, space lawyer Bess Reijnen observed "no immediate solution follows from the obligations formulated in [space] treaties, neither for the clean-up…of existing space debris, nor of the creation of [future] space debris."[70]

Space powers‟ implementation of current UN debris mitigation guidelines has enjoyed mixed success. The US and EU have adopted policies and practices for their space programs that comply with these guidelines.[71] However, there is clear evidence that emerging space powers like China have failed to do so. One IADC guideline from 2002 states:

> Intentional destruction of a spacecraft or orbital stage, (self-destruction, intentional collision, etc.), and other harmful activities that may significantly increase collision risks to other spacecraft and orbital stages should be avoided.[72]

The Chinese National Space Agency was a member of the IADC at the time the IADC approved this guideline in 2002.[73] However, IADC guidelines did not restrain China from conducting its 2007 ASAT test, nor did they result in any international sanctions against China to deter future ASAT tests. Thus, the current voluntary regime has little, if any, enforcement power and is therefore unlikely to achieve the desired endstate.

The second option calls for the development and use of codes of conduct. European space powers signed their own such code in 2006; it applies to space system procurements.[74] Steven Mirmina, a senior attorney at NASA, observed that codes of conduct do not require coordination by governments and they can be used to introduce "best practices" that are later referenced in legal instruments; for example, this was the case with the ISS crew code of conduct which later became enforceable under the ISS Partnership Agreement.[75] There is a measure of enforceability insofar as countries "can condition [contract] award upon compliance with the code."[76] Mirmina sees this option as "a stop-gap measure that would encourage immediate action to reduce the proliferation of new debris, pending more widespread action at the national and international levels."[77] It seems unlikely that mere codes of conduct would be sufficient to enable the space powers to manage the space environment; at best, they can help prevent the creation of new debris through design rules.

The third option is reliance on voluntary bilateral or multilateral agreements..The Missile Technology Control Regime (MTCR) provides a precedent from non-proliferation strategy. Mirmina referred to such an arrangement as a "voluntary adherence regime;" participating governments adhere to MTCR guidelines through national law enforcement. What gives MTCR a stronger quality of enforceability is the legal authority of other MTCR state participants to impose sanctions against exporters of restricted items to proliferators. MTCR sanctions may include blacklisting the exporter from future contracts with the US or blocking it from all federal aid or licenses to purchase weapons from the US.[78] However, if experience with MTCR is an indication as to how successful a voluntary adherence regime for SEM would be, then this option has much to be desired. Iranian compliance with MTCR standards provides scant hope that Iran would willingly adhere to mitigation provisions of an MTCR-like voluntary international agreement for SEM. Technologies used by the Iranian National Space Agency (ISA) during its first autonomous space launch of its Safir-2 rocket in February, 2009 were on the list of items prohibited to Iran by three UN Security Council sanctions resolutions, strongly suggesting the ISA fundamentally places little value in adhering to international norms and guidelines in its race to join the club of space-faring nations.[79] A SEM regime would require a stronger enforcement mechanism than the one the MTCR uses to ensure the compliance of Iran and probably other emerging space powers.

The fourth option is an international SEM treaty with strong enforcement mechanisms over all space powers. Beyond the features previously described to close gaps and shortfalls in the current regime, a treaty would need to implement a SEM regime capable of reducing the risk of debris colliding with active spacecraft. A new international convention, involving both government and industry participants, should implement four broad objectives to achieve that end:

> 1) Implement an international and independent tracking and cataloguing system for space debris; 2) Adopt enforceable space debris mitigation and disposal guidelines; 3) Enforce a space preservation provision for protecting the most vulnerable outer space regions and; 4) Define a space debris compensation and dispute settlement mechanism.[80]

Based on the findings in this paper, to these objectives should be added several additional ones. First, the treaty should include confidence- and security-building measures to ensure that any collisions between debris and active spacecraft, such as the one postulated at the start of this paper, would not result in misunderstanding and international crises. Second, to stimulate commercial development and international cooperation in ADR projects, a space debris treaty should include provisions that facilitate use of ADR technologies under international oversight.

Third, as the 2007 Chinese ASAT test proved, anti-satellite operations can create massive debris fields. Even a small number of kinetic ASAT tests would substantially increase the amount of debris in LEO and further accelerate the rate of cascading collisions. Indeed, the use of an explosive device to intentionally accelerate collisional cascading in order to block access to LEO, as a form of terrorism, blackmail, or sheer anarchism, cannot be ruled out. Even non-kinetic ASAT activities could transform active spacecraft into large chunks of debris that could contribute to catastrophic collisions. Therefore, in light of the danger of the space debris crisis alone, an additional objective for the SEM treaty would be a ban on all ASAT testing in orbit.

Fourth, in much the same way atmospheric environmental conventions apply a “cap and trade” process for managing carbon emissions, a SEM treaty should establish “debris emissions quotas” for at-risk regions of space.[81] It should specify rules and authorities for setting ceilings on new space launches between the space powers to ensure orbital debris populations continuously stay below the cascading tipping point. In orbits already at or beyond that point, the price of any new launches into LEO must be ADR operations.

Finally, in order for the international community to ensure all space powers abide by the treaty, a final provision would need to authorize the UN Security Council to impose economic, political, and potentially military sanctions against space powers that violate the SEM treaty. While the UN has no capacity to enforce sanctions, past UN Security Council Resolutions have made it easier politically for coalitions of nations to band together and act against a truant state. At a minimum, such resolutions have reduced opposition to the use of military force by coalitions.[82]

Space powers, in the framework of the UN, would need to find a way to overcome several significant impediments to completion of a SEM treaty to achieve universal ratification and begin implementing its provisions. Analysis of possible solutions to these is beyond the scope of this paper; these impediments are briefly mentioned to invite future investigation.

First, it is always difficult to negotiate international treaties due to competing national interests. National space program goals to reduce cost, improve orbital presence, protect sensitive proprietary and national security data, maximize freedom of access and movement in space, and test or exercise military space capabilities are just some of the influences that dissuade states from coming to the negotiating table. Before agreeing to a SEM treaty, states must realize that space debris hazards are so great that they justify national concessions to protect sustainable use of space. The compelling data in this paper suggests that this moment has arrived, or will be here shortly.

Second, industrial interests would likely oppose a treaty. Explosion prevention technologies and maneuvering equipment add to the cost of space programs. Effective management of orbital resources likely means rationing of launches and orbital spaces, unless ADR is able to free more room for new spacecraft. Private space companies, whose political power is growing as their presence in the space marketplace expands, would see these design mandates and launch limitations as detrimental to their competitiveness in a crowded space market and likely lobby governments to oppose a SEM treaty. On the other hand, companies producing ADR systems would likely support a SEM treaty.

Third, emerging space powers may see treaty restraints as obstacles to the development of their governmental space programs. A treaty would reduce the range of options for spacecraft design and restrain their freedom to launch into space.[83] States developing offensive counter-space capabilities would likely resist the proposed ban on ASAT testing in orbit.

A fourth challenge would be national concerns regarding sharing of precise SSA data with the UN and the IADC. Use of SSA data by hostile space powers against the interests of the data suppliers could occur in many different ways, particularly if the treaty excludes provisions to ban ASAT testing in orbit. Finding a data sharing standard that balances legitimate national security requirements of space powers with UN needs for SEM and IADC technical requirements for sustainability analysis will be a major challenge.

In retrospect, these four impediments to realizing a SEM treaty are probably the reason no such treaty exists already. Space powers naturally seek to protect their national prerogatives and have sought to limit international restrictions and controls that would tend to limit the range of options for their national or coalition space programs. Because national leaders have begun to comprehend that the space debris crisis is limiting the range of options for their space programs, while driving up operational risks and costs, mankind has reached the moment of truth. The price for continued access to and use of space must be space power submission to an international SEM regime.

Conclusion

The space debris crisis represents a test of mankind‟s ability to govern use of the space environment. The growing mass of man-made space debris in orbit around the planet has already begun to make its presence felt on Earth by disrupting space-based services essential to national security and the comforts of civilization in our networked world. Experts and leaders in the scientific and policy communities are beginning to realize that the international space community must act soon to deal with the problem of congestion in, and competition for, Earth‟s orbits. If the space powers do not establish an effective SEM regime before the quantity of space debris exceeds humanity‟s capability and capacity to control, then mankind‟s access to space could be lost for centuries. Mankind‟s best hope for sustaining its ability to access and operate in space, without fear of major risk from space debris, is an enforceable international treaty on the environmental management of space.

Endnotes

[1] The United Nations defines space debris as "all man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional." United Nations Office for Outer Space Affairs (UNOOSA), "*Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space*, 2010," 1, linked from *UNOOSA Home Page*, http://www.unoosa.org/pdf/publications/st_space_49E.pdf (accessed December 8, 2010)

[2] According to the Outer Space Treaty (OST) of 1967, "States shall be responsible for national space activities whether carried out by governmental or non-governmental activities; States shall be liable for damage caused by their space objects; and States shall avoid harmful contamination of space and celestial bodies." *UNOOSA Home Page, http://www.oosa.unvienna.org/oosa/SpaceLaw/outerspt.html (accessed December 8, 2010).* In addition, the Convention on International Liability for Damage Caused by Space Objects, adopted on November 29, 1971, establishes liability to "pay compensation for damage caused by its space object on the surface of the earth or to aircraft in flight" (Article II) and "in the event of damage being caused elsewhere than on the surface of the Earth to a space object of one launching State or to persons or property on board such a space object by a space object of another launching State, the latter shall be liable only if the damage is due to its fault or the fault of persons for whom it is responsible." (Article III). The question thus arises if a person is at fault if a non-operational space object that they own causes damage to a space object of another person or nation. United Nations, "United Nations Treaties and Principles on Outer Space," 2010, linked from the UNOOSA Home Page at "Convention on International Liability for Damage Caused by Space Objects," http://www.oosa.unvienna.org/oosa/SpaceLaw/liability.html

[3] Jonathan Tirone, "Pentagon warns that space junk poses threat; Report urges steps to prevent collisions with satellites," *The Washington Post*, May 26, 2010, A15.

[4] Patrick K. Gleeson, “Legal Aspects of the Use of Force in Space,” LL.M. Dissertation, McGill University, Canada August, 2005, 1, in ProQuest Dissertations and Theses (accessedJanuary 30, 2011). Gleeson cites as his source: “Our People…Generating Combat Effects from and Through Space,” A speech prepared for General Lance W. Lord, Commander Air Force Space Command Strategic Space Conference, Qwest Center, Omaha NE, on 7 October 2004, Online – Headquarters Air Force Space Command.

[5] National Aeronautics and Space Administration Office of the Chief Technologist Homepage, http://www.sti.nasa.gov/spinoff/database (accessed January 23, 2011).

[6] Per article II of the Outer Space Treaty. *UNOOSA Home Page, http://www.oosa.unvienna.org/oosa/SpaceLaw/outerspt.html* (accessed December 8, 2010)

[7] *Time*, “Science: Slow Death,” January 27, 1958, http://www.time.com/time/magazine/article/0,9171,864206,00.html (accessed February 14, 2011).

[8] Mark Williamson, *Space: The Fragile Frontier* (Reston, Virginia: American Institute of Aeronautics and Astronautics, 2006), 48.

[9] Williamson, 48-53.

[10] National Aeronautics and Space Administration, *Orbital Debris Quarterly News*, April, 2010, vol 14, issue 2, 4, linked from *NASA Orbital Debris Program Office Homepage* at “April, 2010,” http://orbitaldebris.jsc.nasa.gov/newsletter/newsletter.html (accessed November 10, 2010).

[11] Williamson, 52.

[12] Tirone, A15. Recent National Aeronautics and Space Administration (NASA) analysis indicates the number of objects from this crash has grown to 1,740. National Aeronautics and Space Administration, 4.

[13] National Aeronautics and Space Administration, 4.

[14] D.J. Kessler and B.G. Cour-Palais, "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt," *Journal of Geophysical Research*, 83, A6, pp. 2637-2646, June 1, 1978.

[15] National Aeronautics and Space Administration, 4

[16] G.H. Canavan, “Space Debris Hazard to Defense Systems,” Albuquerque, New Mexico: Los Alamos National Laboratory, May 1, 1996, 3, linked from Department of Energy Scientific and Technical Information Portal at http://www.osti.gov/bridge/product.biblio.jsp?query_id=0&page=0&osti_id=238559 (accessed November 20, 2010).

[17] NASA Homepage, http://www.nasa.gov/mission_pages/station/news/orbital_debris.html (accessed December 5, 2010)

[18] *Satellite News*, "Space Debris Situation Becomes Critical for Satellite Operators," Nov 3, 2010, 33, 44, in ProQuest (accessed November 10, 2010).

[19] NASA Homepage.

[20] Ibid. In contrast to the 17,500 mph velocity of object in LEO, small arms fire can range from 613 mph to 2215 mph. See Ron Abramshe, "Improving Ceramic Armor Performance with Better Materials," *Ceramic Industry* 156, no. 10 (October 2006): 14. Given that kinetic energy (in joules) of an object is equal to one half of the mass of an object times the square of its velocity, the energy of a 10 gram object in LEO would be 62.4 times greater than the same mass fired at 2215 mph.

[21] Donald J. Kessler, Nicholas L. Johnson, J.-C. Liou, and Mark Matney, "The Kessler Syndrome: Implications for Future Space Operations," paper presented to the American Astronomical Society, 6 Feb 2010, 7, (http://webpages.charter.net/dkessler/files/Kessler%20Syndrome-AAS%20Paper.pdf) (accessed December 4, 2010.)

[22] Ibid, 7.

[23] Ibid, 11.

[24] Ibid, 12.

[25] Ibid, 13-14.

[26] Ibid, 12.

[27] Richard T. Gavin, "NASA"s Orbital Debris Conjunction Assessment and Collision Avoidance Strategy," February 25, 2010, linked from NASA Technical Reports Server at http://ntrs.nasa.gov/search.jsp?R=812370&id=2&as=false&or=false&qs=Ntt%3Ddebris%257cgavin%26Ntk%3Dall%257call%26Ntx%3Dmode%2Bmatchall%257cmode%2Bmatchall%26Ns%3DHarvestDate%257c1%26N%3D0, (accessed December 5, 2010). Gavin defines a "conjunction" as occurring when a space object is predicted to enter a screening area around a spacecraft. This area is defined as a box with dimensions 4km by 50 km by 50km. It does not imply a physical collision, but it does require consideration of avoidance maneuvers.

[28] Ibid.

[29] Ibid.

[30] Ibid.

[31] CBS News, "Space Station Debris Avoidance Maneuver Carried Out," http://www.cbsnews.com/network/news/space/home/spacenews/files/0cd3a039dc875545f3473124980a1871-89.html (accessed December 5, 2010).

[32] Gavin.

[33] European Space Agency, "Keynote Speech by Jean-Jacques Dordain, Director General of European Space Agency, to the Eurisy conference „Models of Governance of National Space Activities in the Evolving European framework: Optimising Benefits from Participation in European Programmes‟", January 26, 2009, http://www.espi.or.at/images/stories/dokumente/conferences/dordain.pdf (accessed December 5, 2010)

[34] The launch of a Delta IV Heavy Launch Vehicle from Vandenberg Air Force Base, CA on January 20, 2011 had to be "pushed back briefly to avoid an object in space that could have been in the rocket‟s path." See "Large Rocket Launches in California," *Washington Post*, January 21, 2011.

[35] William J. Lynn, "Remarks on Space Policy," Speech, U.S. Strategic Command Space Symposium, Omaha, NE, November 3, 2010, http://www.defense.gov/Speeches/Speech.aspx?SpeechIF-1515 (accessed 10 November 2010).

[36] *Space Daily Home Page*, "More than 1,200 Satellites to be Launched over the Next 10 years," September 7, 2010, http://www.spacedaily.com/reports/More_Than_1200_Satellites_To_Be_Launched_Over_The_Next_10_Years_999.html (accessed 8 December, 2010).

[37] Barack H. Obama, *National Space Policy of the United States of America* (Washington, DC: U.S. Government Printing Office, June 28, 2010), 3.

[38] Ibid, 4.

[39] Frank A. Rose, "2010 Space Symposium – Keynote," November 2, 1010, http://www.stratcom.mil/speeches/2010/55/2010_Space_Symposium_-_Keynote/, (accessed December 15, 2010)

[40] United Nations, iv.

[41] Ibid, 2-4.

[42] Ibid, 2. The member agencies of the IADC include the national space agencies of Italy, France, China, Germany, India, Japan, the U.S., Ukraine, Russia, and United Kingdom, as well as ESA.

[43] Inter-Agency Space Debris Coordinating Committee Homepage, http://www.iadc-online.org/index.cgi (accessed on 6 December, 2010).

[44] Inter-Agency Space Debris Coordinating Committee Homepage, http://www.iadc-online.org/index.cgi?item=torp (accessed on 6 December 2010).

[45] The U.S. Air Force defines SSA as "understanding what your own satellite is doing; understanding what other objects are in space; and understanding what those objects are doing." Lieutenant Colonel Michael D. Gleason, *Space Policy Primer: Principles, Issues, and Actors*, (Colorado Springs, CO: Eisenhower Center for Space and Defense Studies, 2010), 24.

[46] V. Adimurthy, "IADC Protection Manual and IADC Response to UNCOPUOS Request on Internationally Accessible Databases of Objects in Outer Space," Linked from Inter-Agency Space Debris Coordinating Committee Homepage at :IADC Presentation to 47th UNCOPUOS STSC, http://www.iadc-online.org/index.cgi?item=docs_pub (accessed December 6, 2010).

[47] Frank A. Rose, "2010 Space Symposium – Keynote," November 3, 2010, http://www.stratcom.mil/speeches/55/2010_Space_Symposium__Keynote, (accessed December 15, 2010).

[48] Doug Messier, "Australia, United States Team to Protect Vital Space Assets," http://www.parabolicarc.com/2010/11/10/australia-united-states-team-protect-vital-space-assets/ (accessed January 23, 2011).

[49] Inter-Agency Space Debris Coordinating Committee Homepage.

[50] United Nations Office for Outer Space Affairs Homepage, http://www.unoosa.org/oosa/SORegister/regist.html (accessed February 14, 2011).

[51] European Space Agency.

[52] U.S. Congress, House of Representatives, Armed Services Committee, Strategic Forces Subcommittee, *Military Space Programs in Review of the Defense Authorization Request for Fiscal Year 2011 and the Future Years Defense Program*, 111th Cong., 2nd sess., April 21, 2010, 5.

[53] Kevin P. Chilton, "Statement Before the Strategic Forces Subcommittee of the House Committee on Armed Services," (March 16, 2010), http://www.stratcom.mil/posture/ (accessed November 15, 2010).

[54] Ibid.

[55] Williamson, 70.

[56] International Academy of Astronautics, *Cosmic Study on Space Traffic Management*, 2006, 11, linked from http://iaaweb.org/content/view/229/356/ (accessed December 15, 2010)

[57] As recommended by UN Space Debris Mitigation Guideline number 5.

[58] Mark Williamson cites as evidence the 1994 explosion of a U.S. Titan 2 second stage that generated "365 pieces of trackable debris in LEO" that created a potential threat for a space shuttle mission at the time, and a 1996 explosion of a Pegasus upper stage that created 750 pieces of trackable debris at an altitude only 25 km higher than that of the Hubble telescope. Williamson, 49.

[59] James Mackey, "Recent US and Chinese Antisatellite Activities," *Air & Space Power Journal*, no. 23 (Fall 2009): 82-93 in ProQuest (accessed December 8, 2010). Mackey cites as source for this: Office of the Secretary of Defense, Military Power of the People's Republic of China 2008: A Report to Congress pursuant to the National Defense Authorization Act, Fiscal Year 2000 (Washington, DC: Department of Defense, 2008), http://www.defense link.mil/pubs/pdfs/China_Military_Report_08.pdf (accessed 2 November 2008).

[60] NASA Orbital Debris Program Office Homepage, http://orbitaldebris.jsc.nasa.gov/faqs.html (accessed on December 15, 2010).

[61] International Academy of Astronautics, "Position Paper on Space Debris Mitigation: Implementing Zero Debris Creation Zones," October 15, 2005, http://iaaweb.org/iaa/Studies/spacedebrismitigation.pdf (accessed on January 23, 2011).

[62] Janovsky, M. Kassebom, H. Luebberstedt, O. Romberg, H. Burkhardt, M. Sippel, G. Kruelle, B. Fritsche, "End-of-Life De-orbiting Strategies for Satellites," 2002, 9-10 linked from *The DLR Institut fuer Raumfahrtantriebe Systemanalyse Raumtransport (SART) Homepage* at "Publications," http://www.la.dlr.de/ra/sart/projects/eol/eol.php.en (accessed January 31, 2011).

[63] Ibid.

[64] Kevin Johnson and John G. Hudson, "Eliminating Space Debris: Applied Technology and Policy Prescriptions," January 2008, 78, linked from *The Defense Technical Information Service Homepage* at http://www.dtic.mil/dtic/ (accessed January 30, 2011).

[65] Lieutenant Colonel Gregory D. Hillebrand, U.S. Air Force, interview by author, Carlisle, PA, October 20, 2010.

[66] Johnson and Hudson, 89-111.

[67] National Aeronautics and Space Administration, 7.

[68] United Nations, "Report of the Legal Subcommittee on its Forty-Ninth Session, held in Vienna from 22 March to 1 April 2010," April 16, 2010, 21, http://www.oosa.unvienna.org/pdf/reports/ac105/AC105_942E.pdf (accessed January 27, 2011)

[69] Michael P. Gleason, *Space Policy Primer: Principles, Issues and Actors* (Colorado Springs, Colorado: US Air Force Academy, 2010), 28-30, http://web.mac.com/rharrison5/Eisenhower_Center_for_Space_and_Defense_Studies/Space_Policy_Primer_files/Space%20Policy%20Primer%20022810.pdf (accessed October 25, 2010).

[70] Williamson, 176.

[71] Examples of US policies and practices include "US Government Orbital Debris Mitigation Standard Practices," 1997, "NASA Procedural Requirements for Limiting Orbital Debris," 2007, and NASA Technical Standard 8719.24, 2007. See http://orbitaldebris.jsc.nasa.gov/mitigate/mitigation.html (accessed January 30, 2011). ESA policies and practices include "ESA Space Debris Mitigation Guidelines," April, 2008, linked from: http://www.esa.int/SPECIALS/Space_Debris/SEMQHL05VQF_0.html (accessed January 30, 2011).

[72] Inter-Agency Space Debris Coordination Committee, "IADC Space Debris Mitigation Guidelines Revision 1," September 2007, 9, linked from http://www.iadc-online.org/index.cgi?item=docs_pub (accessed on January 30, 2011).

[73] Inter-Agency Space Debris Coordination Committee, “Report of the IADC Activities on Space Debris Mitigation Guidelines,” 2, linked from http://www.iadc-online.org/index.cgi?item=docs_pub (accessed on January 30, 2011).

[74] European Space Agency Homepage, http://www.esa.int/esaMI/Space_Debris/SEMQHL05VQF_0.html (accessed 27 January 2011).

[75] Steven A. Mirmina, “Reducing the Proliferation of Orbital Debris: Alternatives to a Legally Binding Instrument,” *The American Journal of International Law* 99, no. 3 (July 2005), in ProQuest (accessed January 15, 2011).

[76] Ibid.

[77] Ibid.

[78] Ibid.

[79] Peter Crail, “Iran Makes First Successful Space Launch,” *Arms Control Today 39*, no. 2 (March 2009): 42-43, in ProQuest (accessed December 15, 2010).

[80] Thierry Senechal, “Orbital Debris: Drafting, Negotiating, Implementing a Convention,” June, 2007, 2, http://mit.edu/stgs/pdfs/Orbital%20Debris%20Convention%20Thierry%20Senechal%2011%20May%202007.pdf (accessed November 10, 2010).

[81] Ibid, 105.

[82] UN Security Council Resolutions began to have real power in forging coalitions against misbehavior by states during the first Gulf War. In November, 1990, UN Security Council Resolution 678 gave Saddam Hussein a deadline of January 15, 1991 to withdraw Iraqi troops from Kuwait, and authorized a US-led coalition to throw them out if he did not. This resolution helped the US to not only build its coalition against Iraq, but also reduced international opposition to the use of force against Iraq and allowed the coalition to establish a deadline for the ultimatum. See Alvin Z. Rubenstein, “New World Order of Hollow Victory?” *Foreign Affairs*: 70, no. 4 (Fall 1991): 53-58 in ProQuest (accessed January 30, 2011).

[83] Eisenhower Institute, *Space Security 2003*, (Washington: The Eisenhower Institute, 2004), 8, http://www.spacesecurity.org/SSI2003.pdf (accessed December 15, 2010).